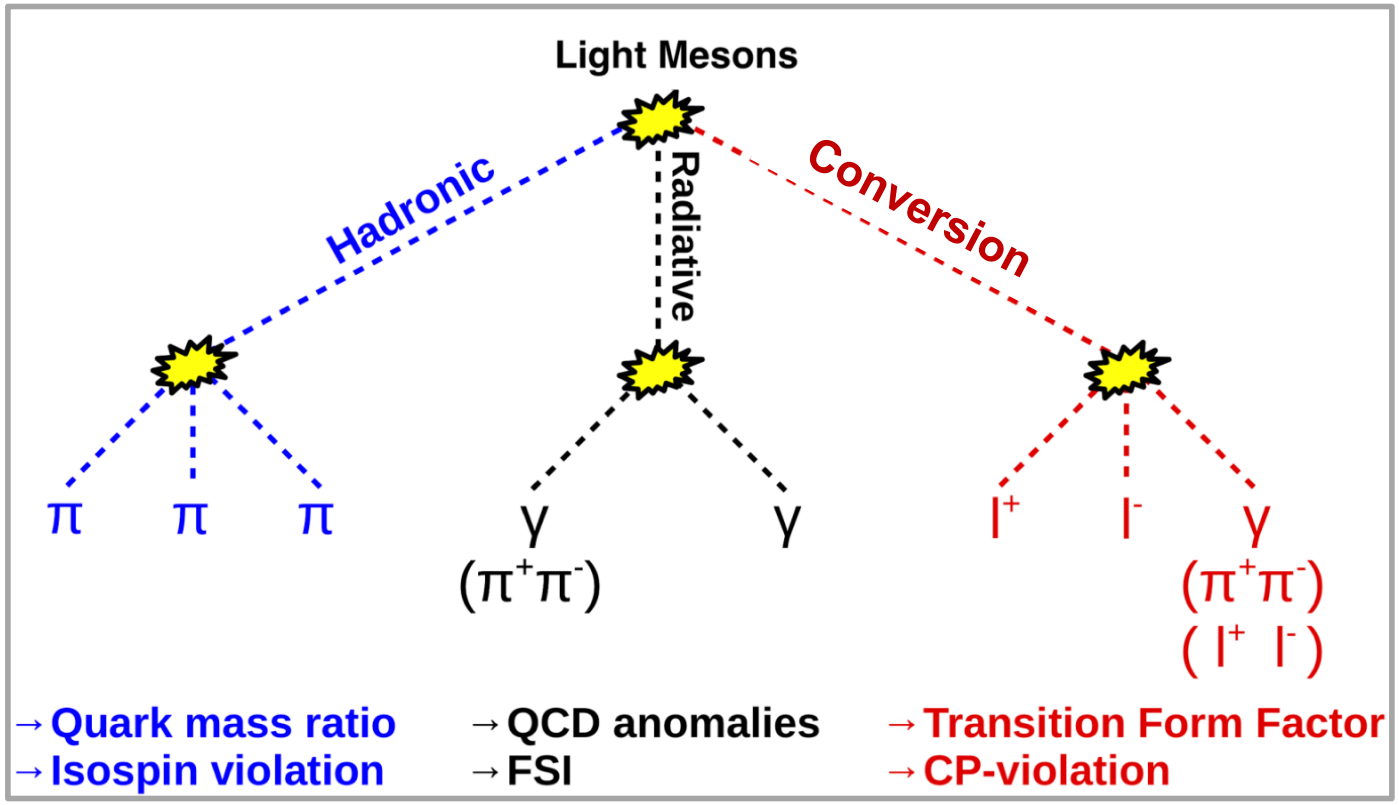
Light Meson Decays

upcoming analysis reports on the decays $\eta \rightarrow \pi^0 \pi^+\pi^-$ and $\omega \rightarrow \pi^0 e^+e^-$

CLAS Collaboration Meeting

March 2018 I Jim Ritman

Light Meson Decays



WASA-at-COSY: π, η

the orginal proposal for bringing WASA to COSY :

Proposal for the wide angle shower apparatus (WASA) at COSY-Julich: WASA at COSY
WASA-at-COSY Collaboration, e-Print: **nucl-ex/0411038**

CLAS: π, η, ω, η‘

the orginal proposal:
CAA Photoproduction and Decay of Light Mesons in CLAS
https://wiki.jlab.org/lmd/

CLAS approved analysis CAA-LMD

active analyses

hadronic decays: Dalitz plot analysis			
$\eta \to \pi^0 \pi^+ \pi^-$	g12	Daniel Lersch	• analysis report in progress
$\omega \to \pi^0 \pi^+ \pi^-$	g12	Chris Zeoli	• PhD 2016 FSU
$\eta' \to \eta \pi^+ \pi^-$	g12	Sudeep Ghosh	• analysis report submitted
PWA of $\pi^+ \pi^- \eta$	g12	Cathrina Sowa	• PhD 2016 RU-Bochum
radiative decays: box anomaly, branching ratio			
$\eta' \to \pi^+ \pi^- \gamma$	g11	Georgie Mbianda Njencheu	• analysis report submitted • PhD 2017 ODU
$\eta \to \pi^+ \pi^- \gamma$	g11	Torri Roark	
$\rho \to \pi^+ \pi^- \gamma$	g11	Tyler Viducic	
conversion decays: electromagnetic transition form factor			
$\pi \to \gamma e^+ e^-$	g12	Michael Kunkel	• paper submitted on π^0 x-section • PhD 2014 ODU
$\omega \to \pi^0 e^+ e^-$	g12	Susan Schadmand	
$\eta' \to \gamma e^+ e^-$	g12 CLAS12	Michaela Schever Michael Kunkel	• Master 2015, RWTH Aachen • proposal

Hadronic Decays

$\eta \to \pi^+\pi^-\pi^0$

probing isospin violation (for pseudoscalar mesons)
+ hadronic final-state interactions

access to light quark mass ratios

$$Q^2 = \left(\frac{m_s}{m_d}\right)^2 \times \left[1 - \frac{m_u}{m_d}\right]^{-1}$$

extract from decay width

H. Leutwyler PLB378(1996)313

$$\Gamma = \left(\frac{Q_D}{Q}\right)^4 \bar{\Gamma}$$

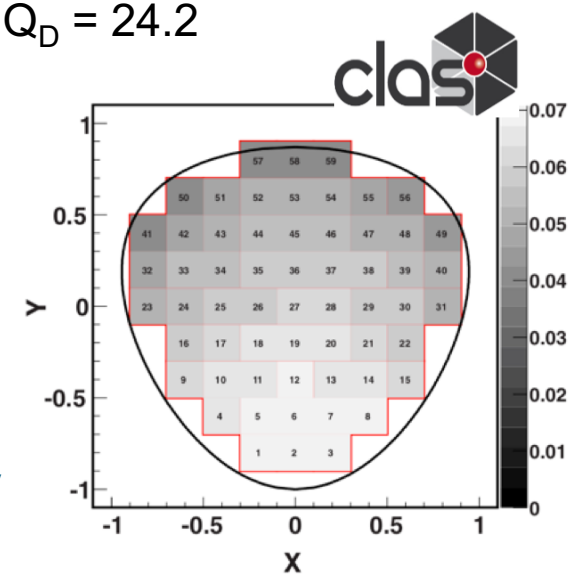
decay width Dashen limit $Q_D = 24.2$

test with experimental Dalitz plot distributions

$$\frac{d\Gamma}{dXdY} \propto |A(X,Y)|^2 \propto 1 + aY + bY^2 + dX^2 + fY^3 + \ldots$$

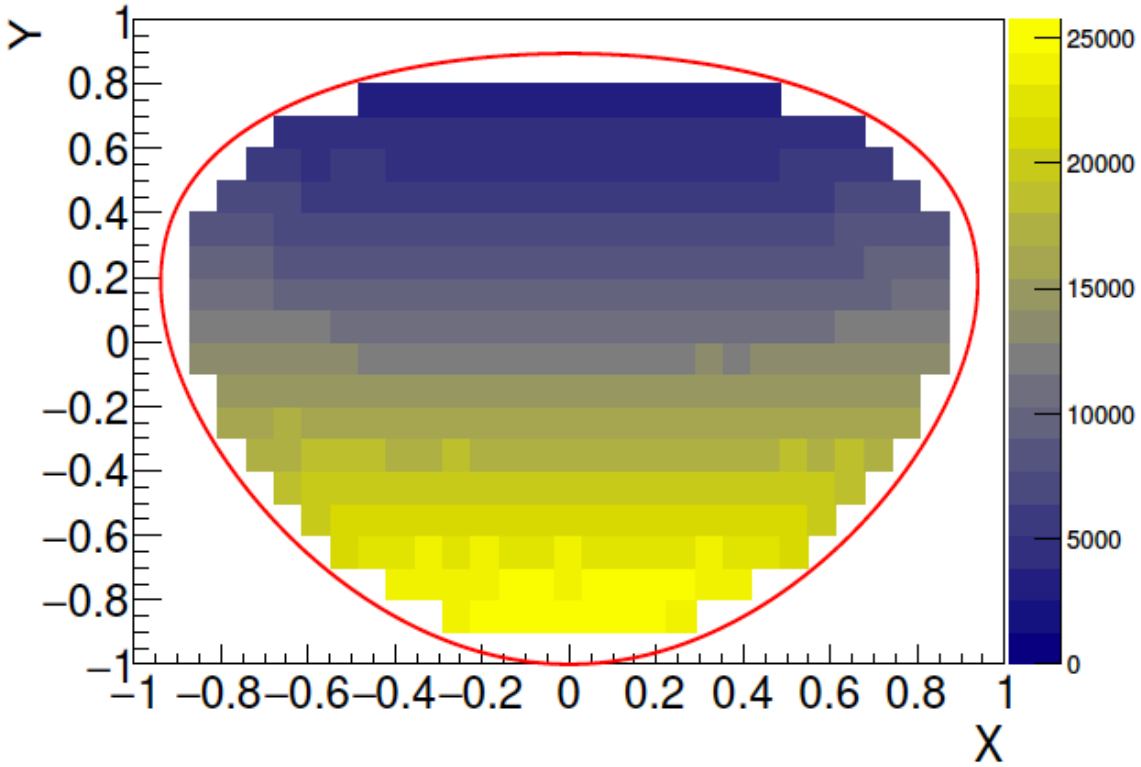
$$X = \sqrt{3}\frac{T_+ - T_-}{T_+ + T_- + T_0} \qquad Y = \frac{3T_0}{T_+ + T_- + T_0} - 1$$

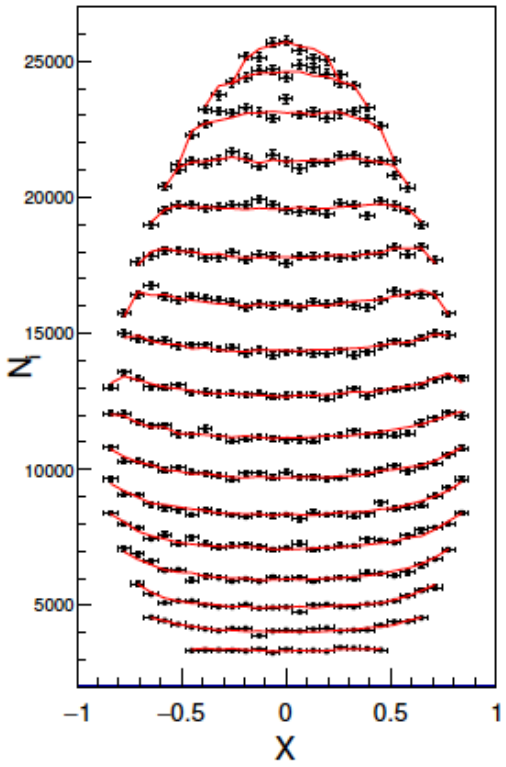
expansion
Dalitz plot density



Decay amplitude A related to light quark mass ratios via Q^2
PWA to extract Q, and a,b,d,f

Recent Measurements I





KLOE: $Q = 21.7 \pm 1.1$

Most recent result from the KLOE-Collaboration:[(f)]

- η-Mesons produced via: $e^+e^- \to \Phi \to \eta\gamma$
- $\approx 4.7 \cdot 10^6$ $\eta \to \pi^+\pi^-\pi^0$ events in the final data sample
- Fit function: Norm $\times (1 + aY + bY + cX + dX^2 + eXY + fY^3)$
- Determined asymmetries of the Dalitz Plot $\Rightarrow$ Consistent with zero
  $\Rightarrow$ No C-violation

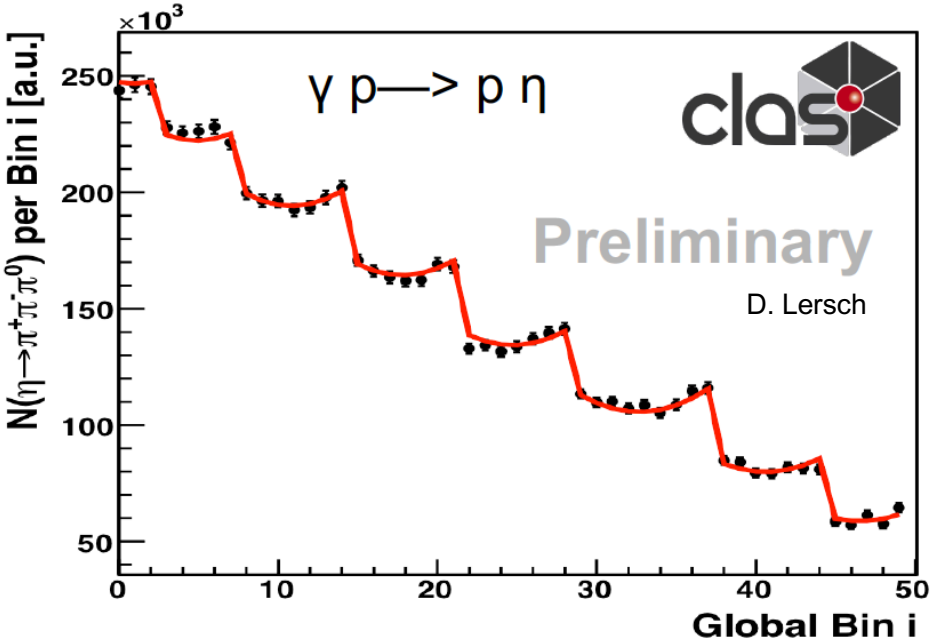
(f) KLOE coll., *JHEP*, 019, (2016)

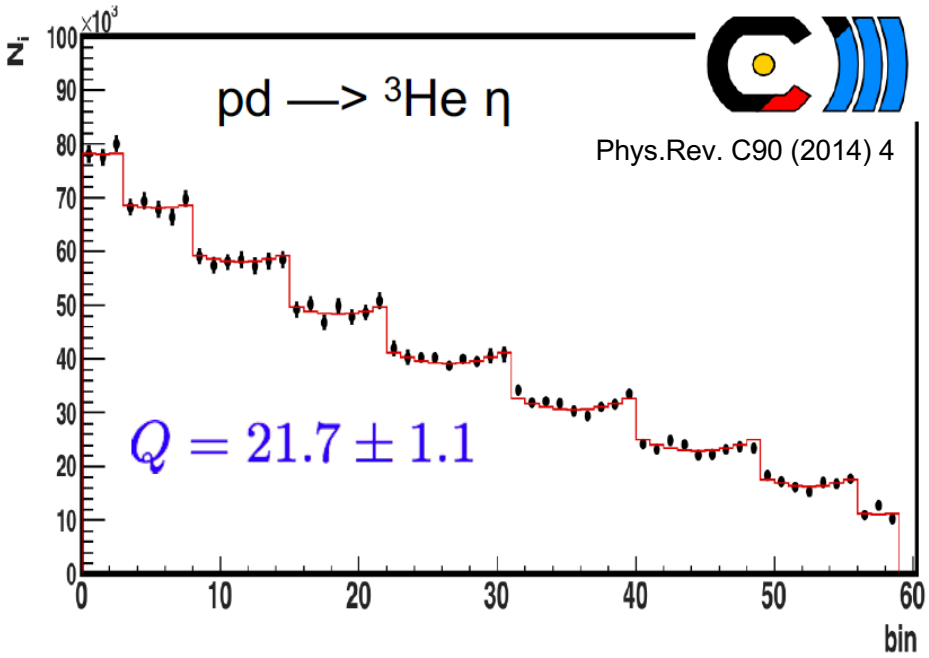
Hadronic Decays

$\eta \rightarrow \pi^+\pi^-\pi^0$

Isospin breaking in the strong interaction

Decay amplitude A related to light quark mass ratios via Q^2





Decay amplitude via Dalitz-Plot-Analysis: A = f (X,Y)

Q from dispersive model analysis of KLOE&WASA, P. Guo et al.

Summary and Outlook

- Refined error estimation ⇒ Errors are in a more "reasonable" range
- Need to include into error-estimation:
  - Variation of photon beam energy range
  - Leaving out "sensitive" data points → Turned out to have an effect on f
  - Correlation of errors
- Statistical error depends on number of Dalitz Plot bins
  ⇔ Finer binning?

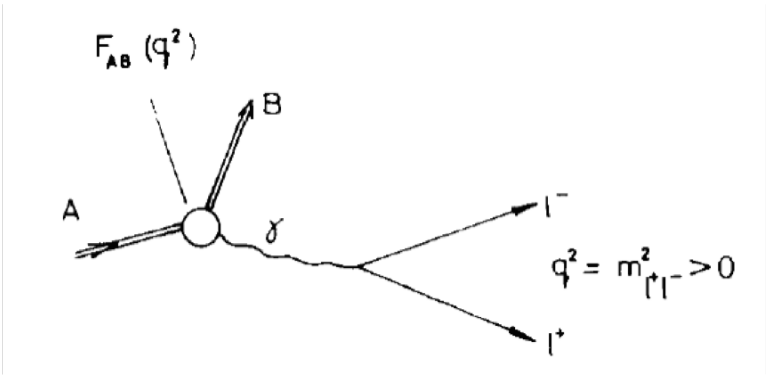
Parameter	-a	b	c	d	f
KLOE(08)	$1.090(5)(^{+8}_{-19})$	0.124(6)(10)	0.0	$0.057(6)(^{+7}_{-16})$	0.14(1)(2)
WASA	1.144(18)	0.219(19)(47)	0.0	0.086(18)(15)	0.115(37)
KLOE(16)	1.104(5)(2)	$0.142(3)(^{+5}_{-4})$	0.0	$0.073(3)(^{+4}_{-3})$	$0.154(6)(^{+4}_{-5})$
G12	1.102(20)(13)	0.127(18)(5)	0.011(7)(7)	0.106(19)(5)	0.248(45)(10)

Stefan Leupold
Uppsala University

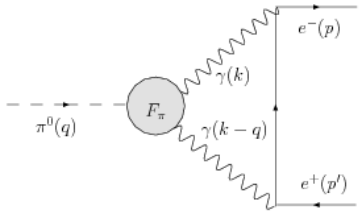
Conversion Decays

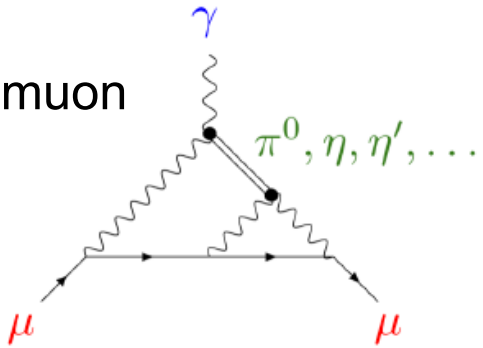
Reactions of hadrons with virtual photons

- intrinsic structure of hadrons
  - transition form factors
  - validity of vector meson dominance



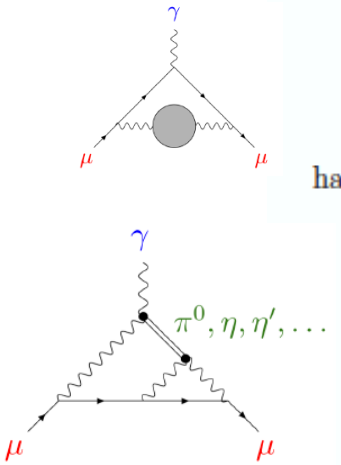
- background for physics beyond the standard model
  - rare decays
    - e.g. $\pi \to ee$
  - g-2 anomalous magnetic moment of the muon
    - light-by-light scattering

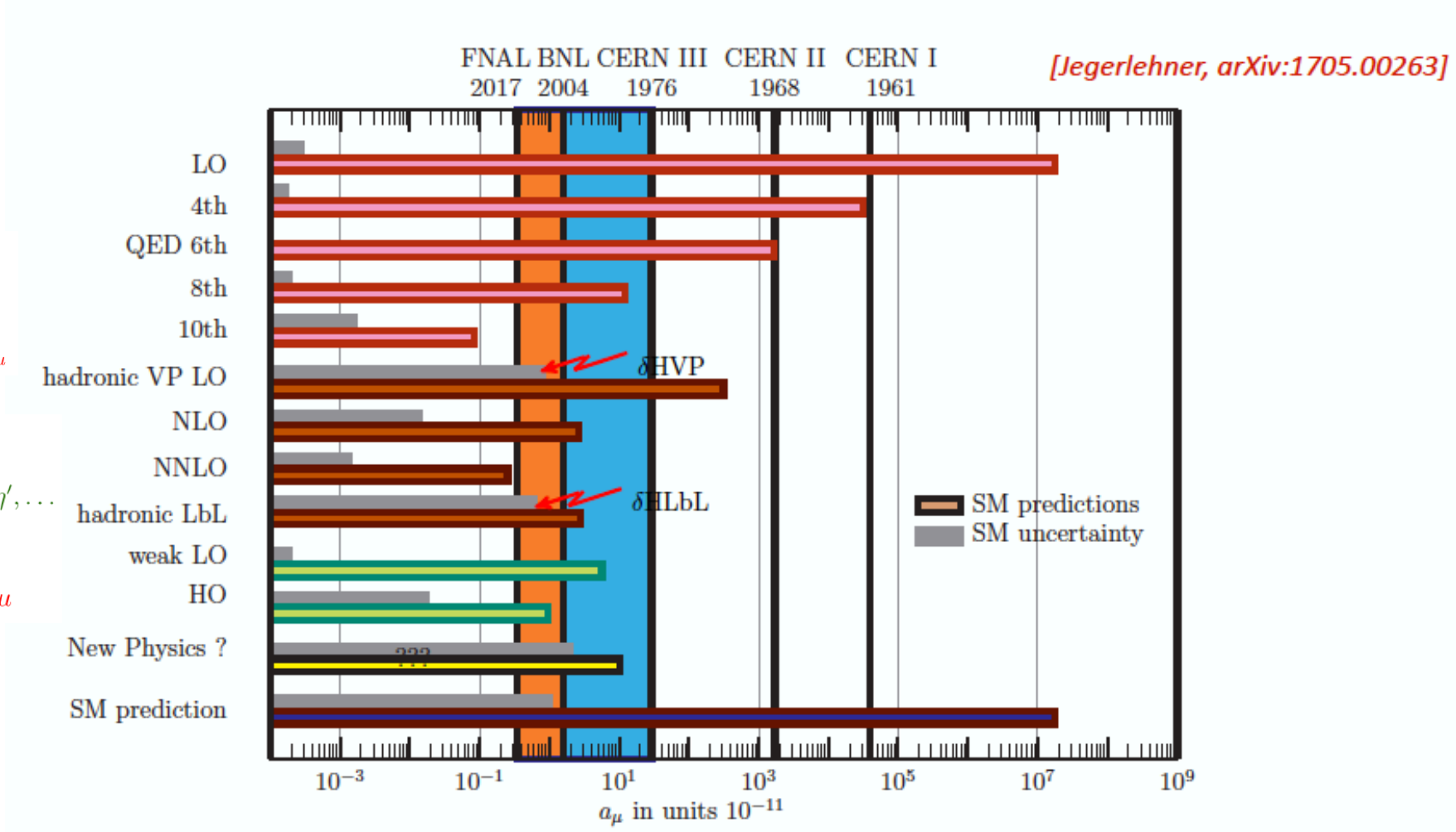




Theory confronts Experiment

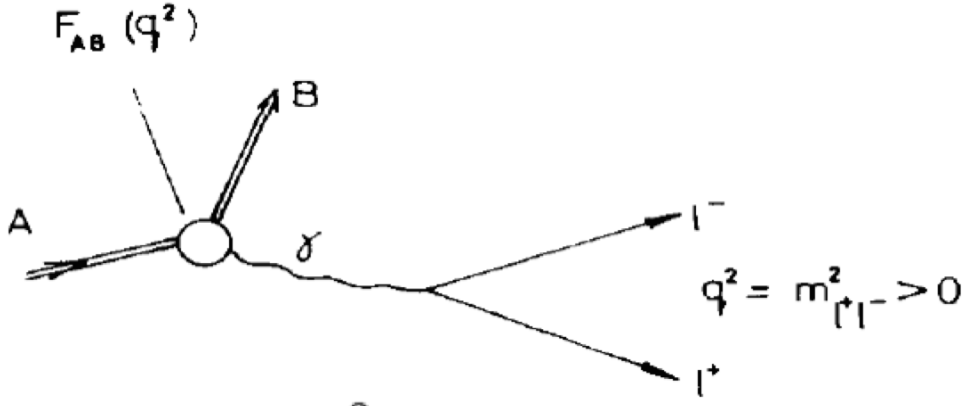
Role of hadronic decays for g-2





Conversion Decays

Transition Form Factors



$$\frac{d\Gamma(A \to B\, l^+ l^-)}{dq^2 \cdot \Gamma(A \to B\gamma)} = \left|F_{A\to B}(q^2)\right|^2 \cdot |\mathrm{QED}|$$

$$F_{AB}(q^2) = [1 - q^2/\Lambda^2]^{-1}$$ (single) pole approximation

$$F_{AB}(q^2) \simeq 1 + q^2[\mathrm{d}F_{AB}/\mathrm{d}q^2]|_{q^2\simeq 0} = 1 + q^2 b_{AB} = 1 + \tfrac{1}{6}q^2\langle r^2_{AB}\rangle$$

$$\Lambda \simeq m_\rho \; (\Lambda^{-2} = b_{AB})$$

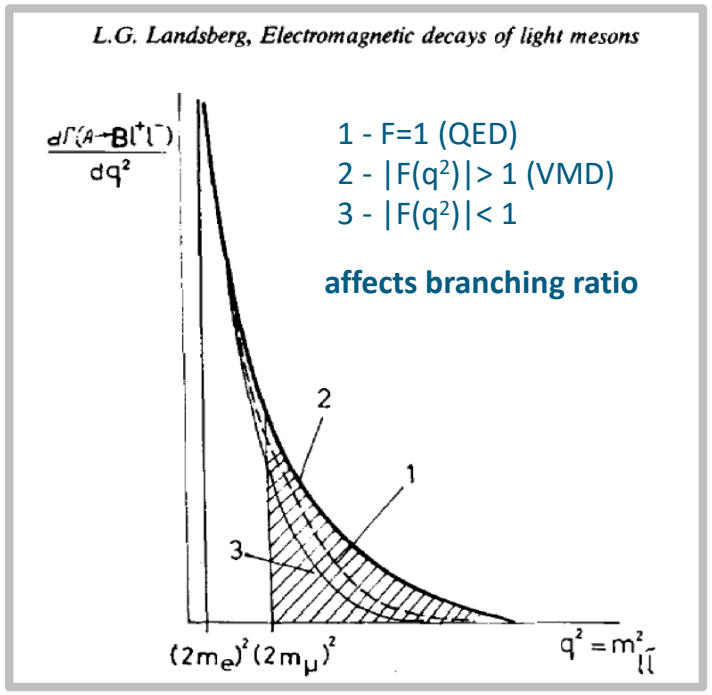
'standard' VMD, b~1.69/GeV^2

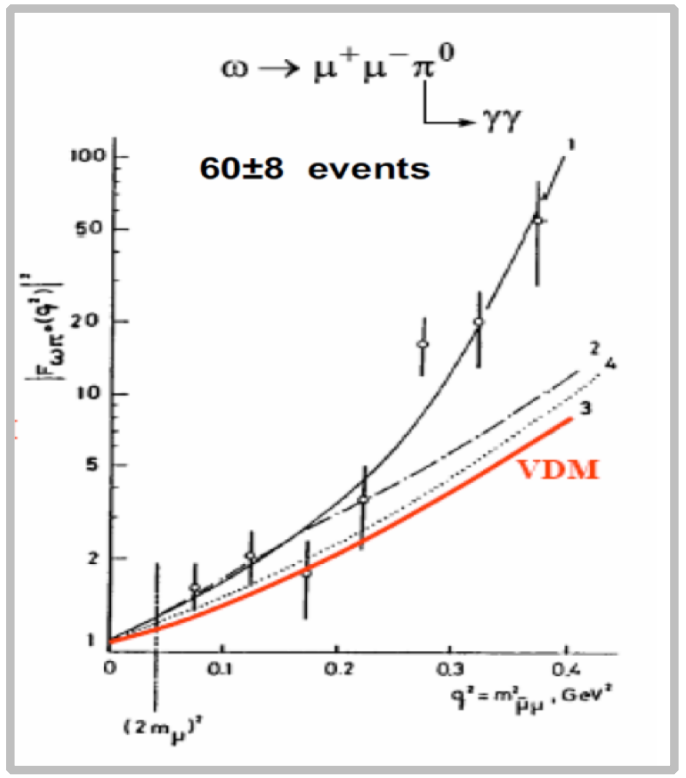
slope parameter

size (transition region)

Conversion Decays

Transition Form Factors



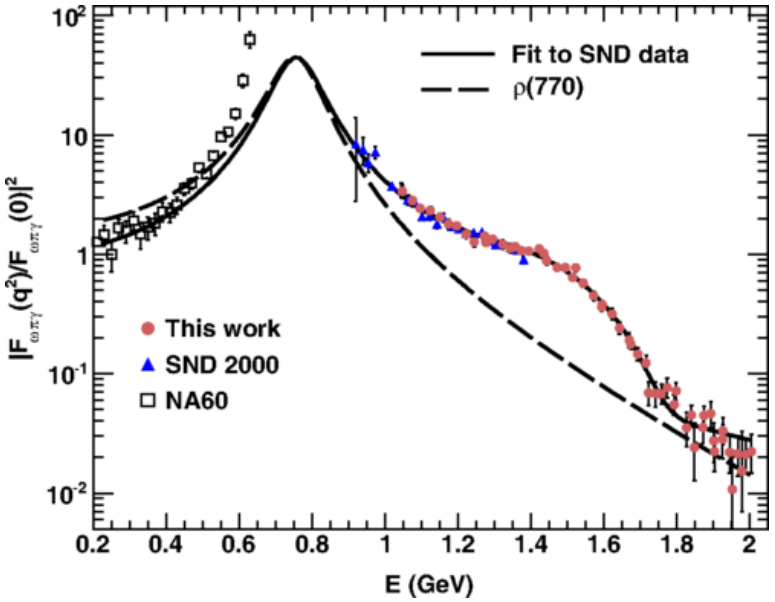


form factor: divide experimental q^2 distribution by QED

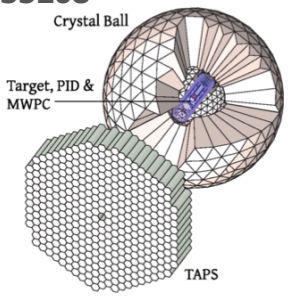
$$\Lambda \simeq m_\rho \ (\Lambda^{-2} = b_{AB})$$ 'standard' VMD, b~1.69/GeV^2

status of the ω-π transition form factor

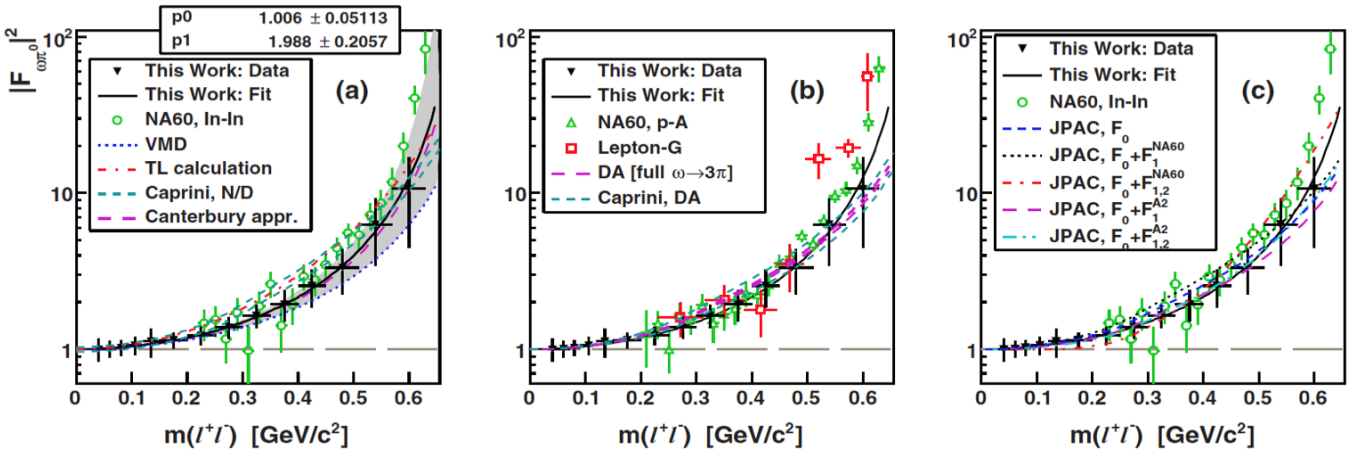
M. N. Achasov *et al.*, Phys. Rev. D 94, (2016) 112001



S. Prakhov (A2 Collaboration at MAMI)
Phys. Rev. C 95, 035208



$\Lambda^{-2}=(1.99\pm0.21_{tot})$ GeV^{-2}
1100 overall statistics

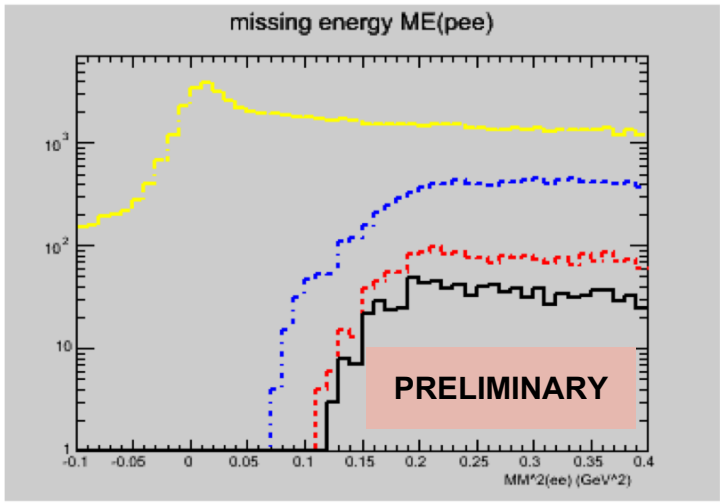


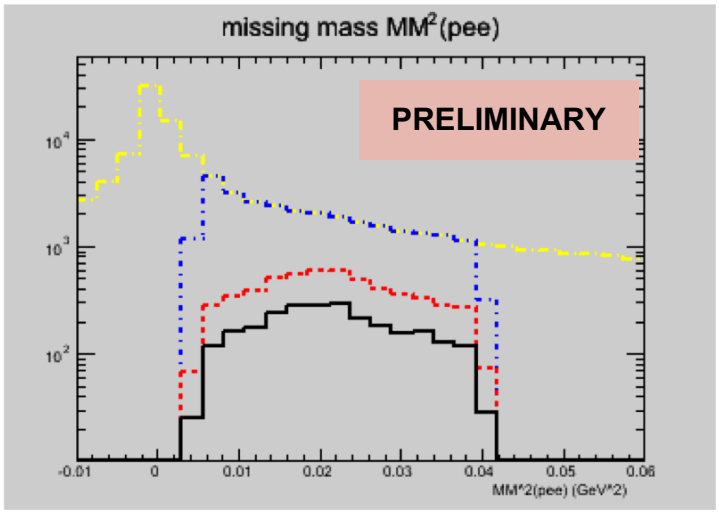
conclusion:

- A2 results are in better agreement with theoretical calculations, compared to earlier experiments
- statistical accuracy of the present data points at large m (ee) masses does not allow a final conclusion

ω-π^0 Transition Form Factor

analysis strategy cut-based analysis





e^+e^- detection
and missing particle

missing pion: **$\omega \rightarrow \pi ee$**
- missing mass is pion mass
- missing energy finite

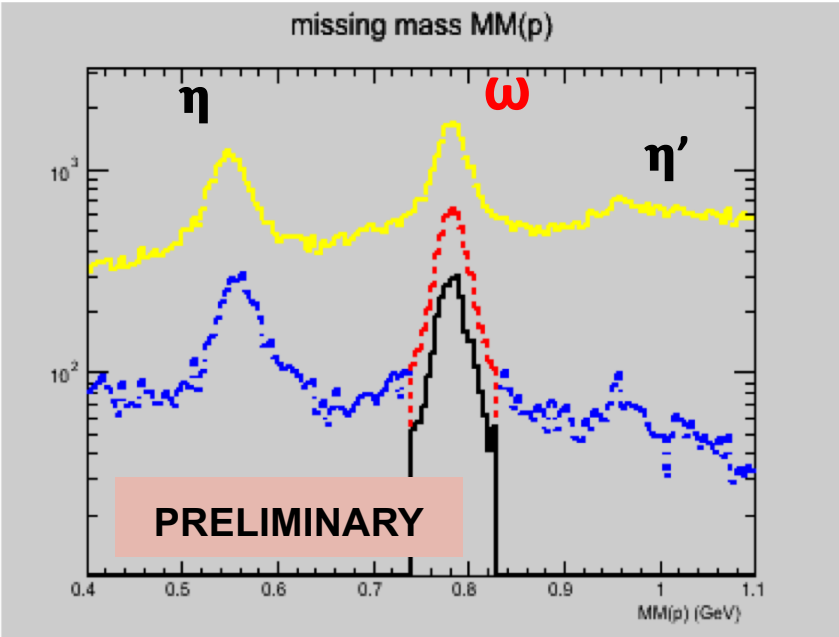
missing photon: **$\eta(') \rightarrow \gamma ee$**
- missing mass zero
- missing energy finite

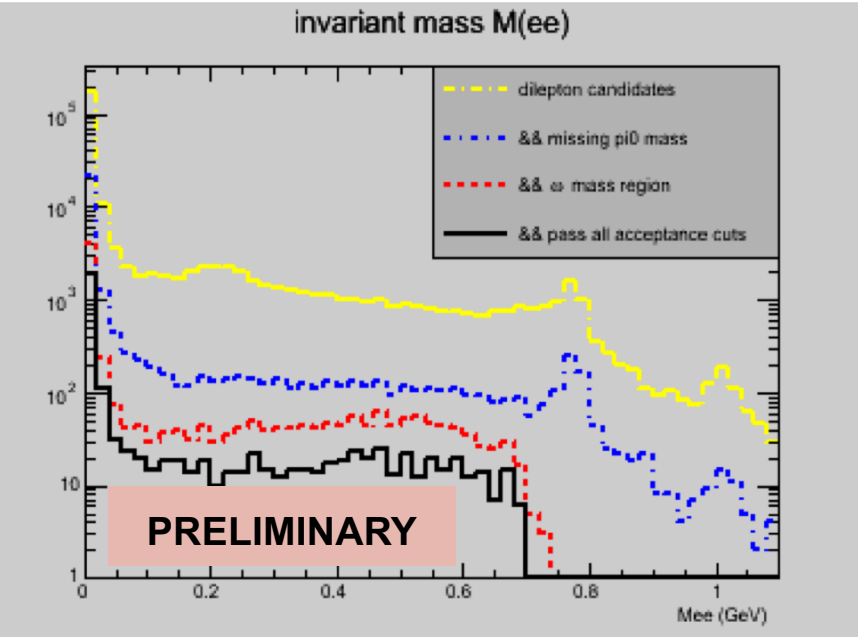
missing nothing: **$\rho/\omega \rightarrow ee$**
- missing mass zero
  missing energy zero

missing mass cut is crucial

ω-π^0 Transition Form Factor

CLAS-g12 analysis* ω→πee candidates



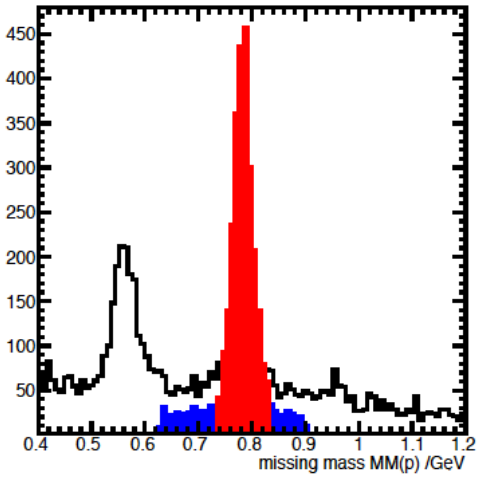


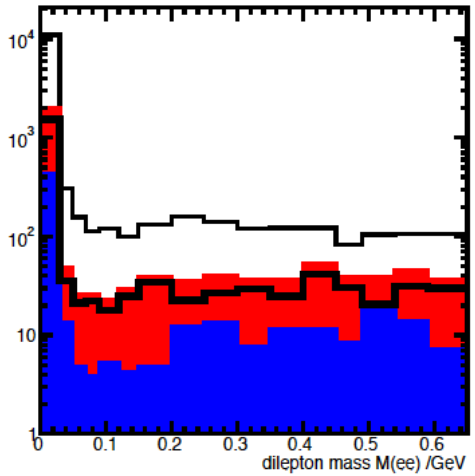
- smooth background ← fit and subtract
- in-peak background (competing decays) ← simulations
- photon conversion from $\pi \rightarrow \gamma\gamma$ ← simulations, small ee masses

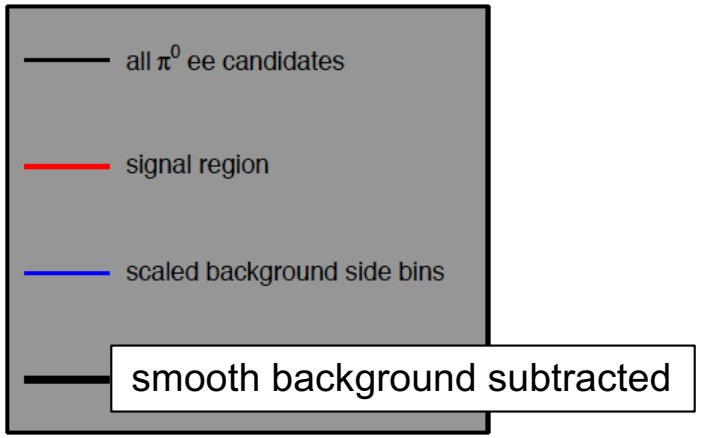
* based on dilepton analysis of M.C.Kunkel

ω-π^0 Transition Form Factor

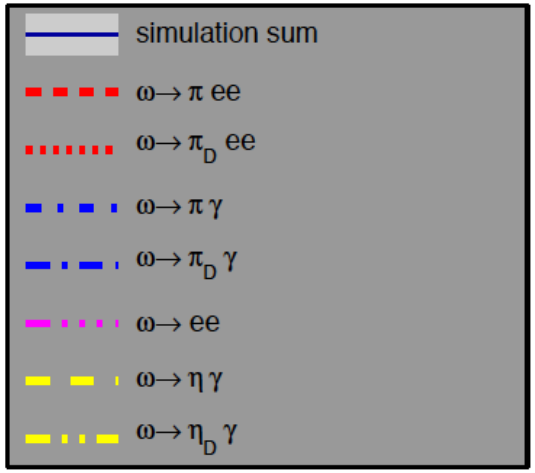
sideband background subtraction

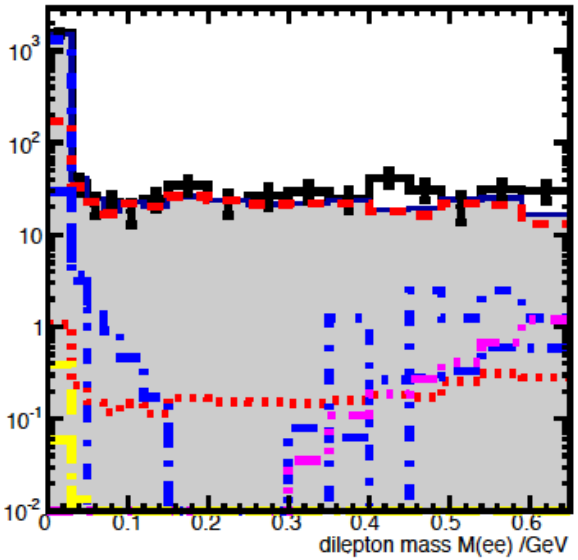






in-peak background



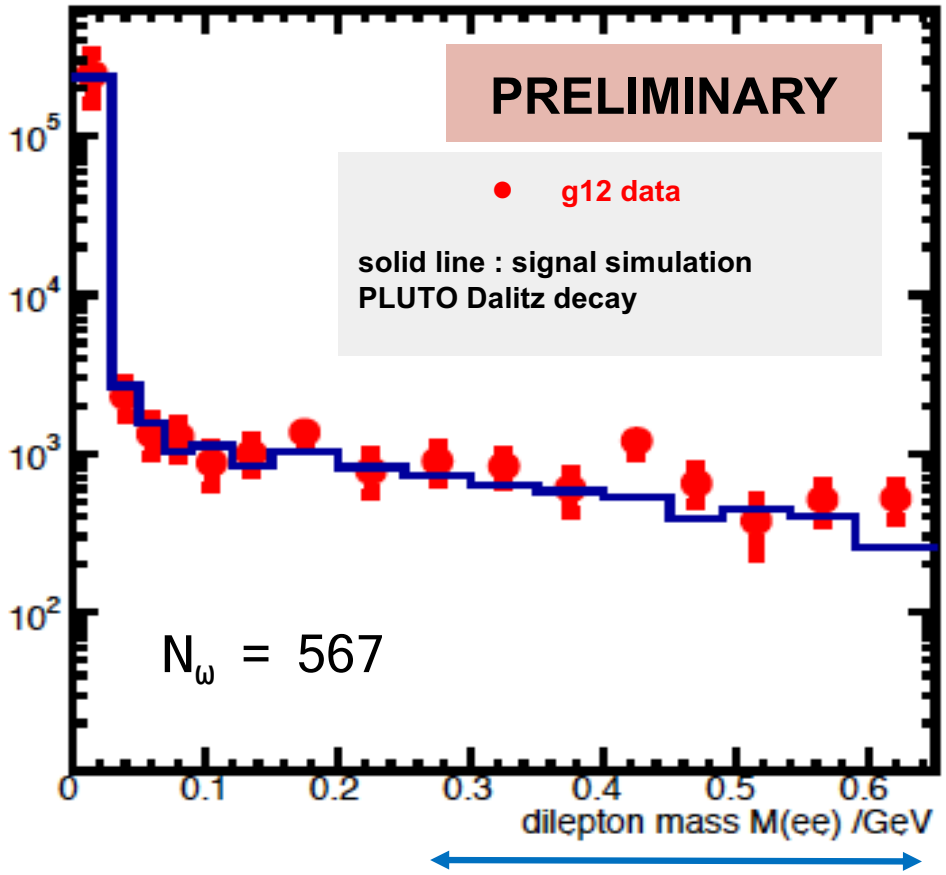


simulations for
in-peak background reveal:

- **external conversion** at small masses
- **combinatorics** at large masses

ω-π^0 Transition Form Factor

dilepton mass distribution



region of interest
influence of combinatorics

dilepton mass distribution

- (both) background types subtracted
- efficiency corrected
- integrated over tagger range

  1.1-5.5GeV

trend:

- no extreme excess beyond standard VMD?

issues:

- limited statistics at high-mass end
- combinatorics

towards TFF:

- divide by QED reconstructed simulation
- event-wise un-weighting by flux

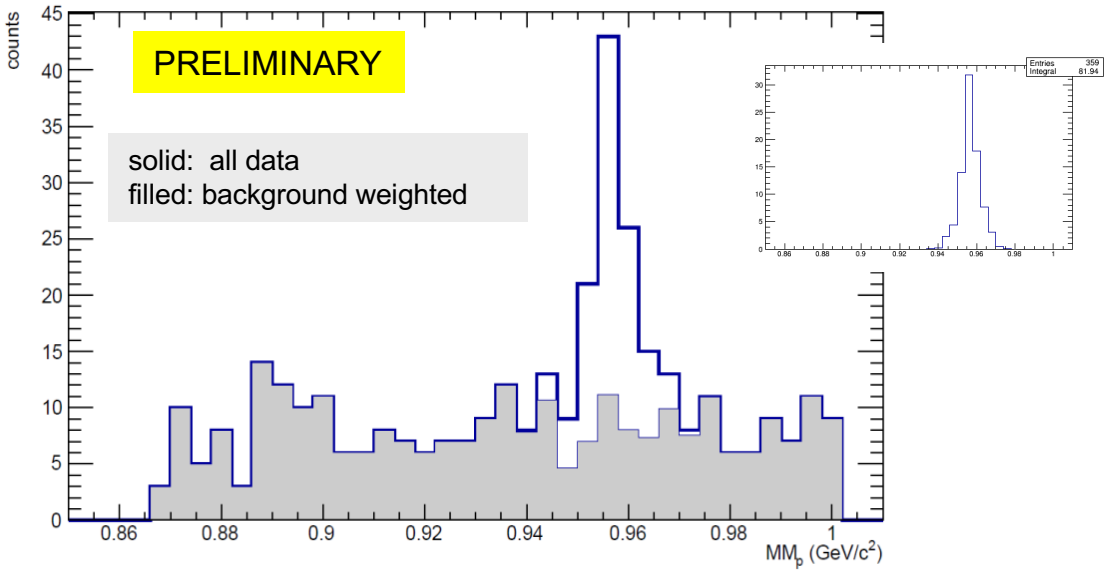
$\eta' \to \gamma ee$: Exploratory Analysis

- CLAS g12 experiment
- data analysis: g12 procedures
- Cut based analysis
- q-factor signal extraction:
  evaluate smooth background event-by-event

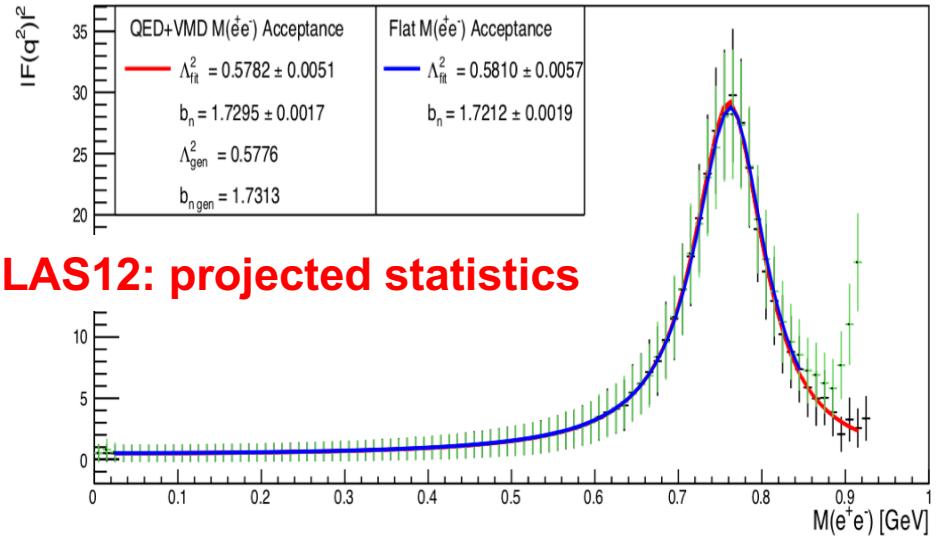
➢ 359 event candidates

➢ **82 events (signal weight)**

CLAS6 not competitive with BESIII
(observed signal events 864 ± 36)



CLAS12: projected statistics



Summary

decays of light mesons

- CLAS g12 experiment
  - π^0, η, η', and ω decays
  - planning new analysis
    - use of kinematic fit
    - statistics
    - combinatorics

- CLAS12 campaigns:
  - η' decays proposed
  - other proposals to come

physics landscape needs the results

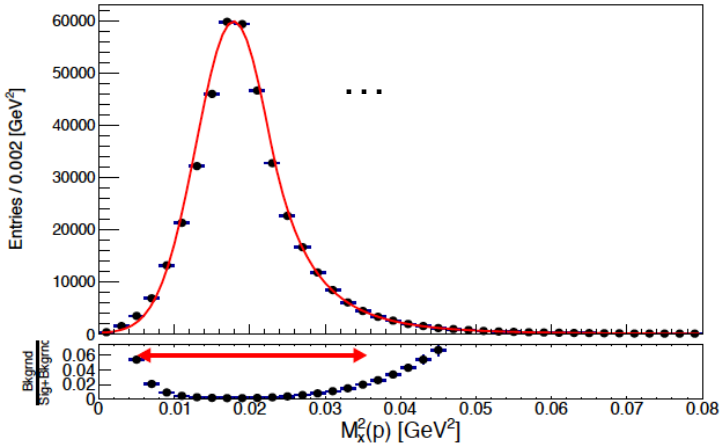
March 2018

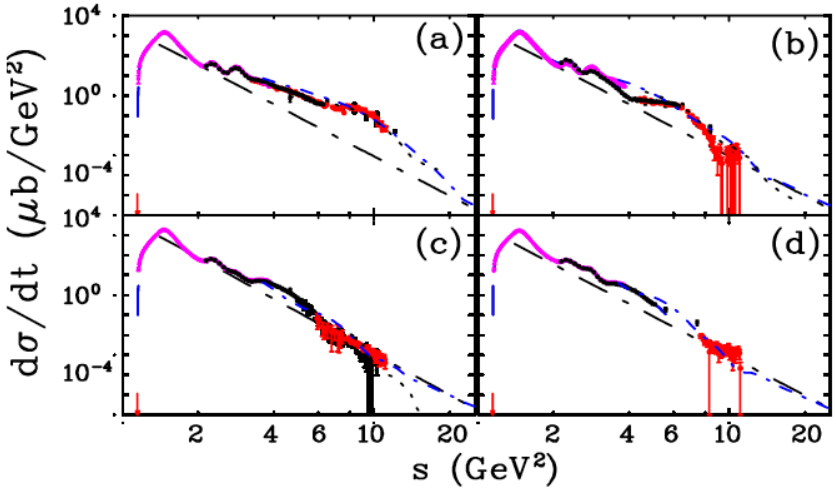
pi0 xtras

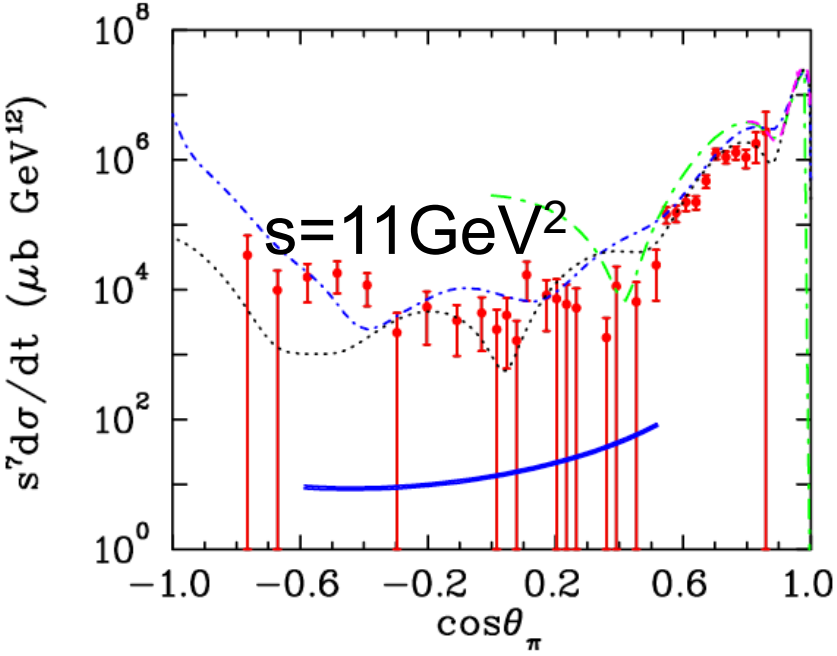
Exclusive π^0 Photoproduction

PhD thesis M.C.Kunkel
paper submitted

very clean sample





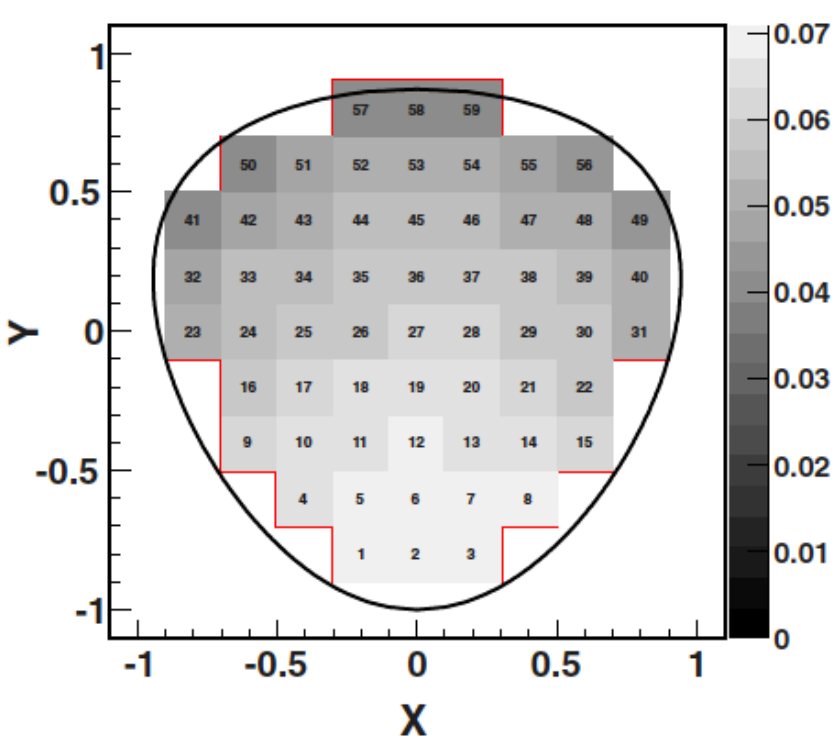


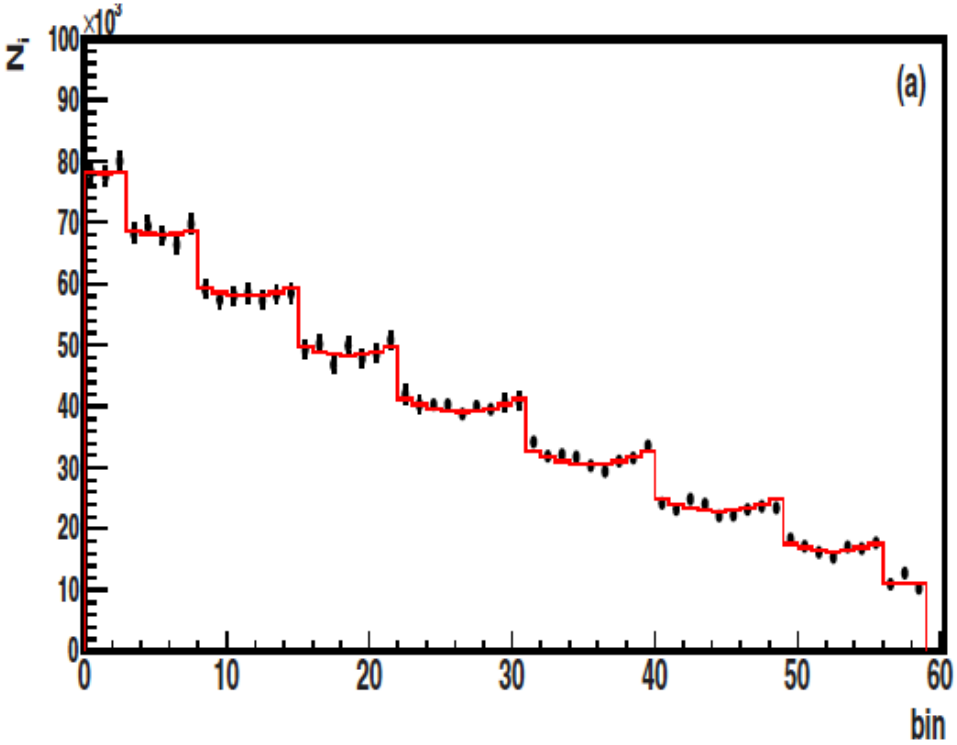
angular distribution consistent with Regge-based model

cross section scales with s.e-7
consistent with perturbative QCD quark counting rules

eta
xtras

Recent Measurements II





Result from the WASA-at-COSY Collaboration:[(d)]

- η-Mesons produced via: $pd \rightarrow {}^3\mathrm{He}\eta$
- $\approx 120\,\mathrm{k}\ \eta \rightarrow \pi^+\pi^-\pi^0$ events in the final data sample
- Translate each pair (X,Y) into a global bin $i(X, Y)$
  $\rightarrow$ Obtain one dimensional Dalitz Plot
- Fit function: Norm $\times (1 + aY + bY + cX + dX^2 + eXY + fY^3)$

(d) WASA-at-COSY coll., *Phys. Rev.*, C90(045207), 2014

Recent Measurements and Theoretical Predictions

	Parameter:	− a	b	d	f
Exp.	KLOE (08)[a]	$1.090(5)(^{+8}_{-19})$	0.124(6)(10)	$0.057(6)(^{+7}_{-16})$	0.14(1)(2)
	WASA[d]	1.144(18)	0.219(19)(47)	0.086(18)(15)	0.115(37)
	KLOE (16)[f]	$1.104(3)(2)$	$0.142(3)(^{5}_{-4})$	$0.073(3)(^{+4}_{-3})$	$0.154(6)(^{+4}_{-5})$
Theor.	ChPT (NNLO)[b]	1.271(75)	0.394(102)	0.055(57)	0.025(160)
	NREFT[c]	1.213(14)	0.308(23)	0.050(3)	0.083(19)
	PWA[e]	1.116(32)	0.188(12)	0.063(4)	0.091(3)
	PWA[g]	1.077(29)	0.170(8)	0.060(2)	0.091(3)

(a) KLOE coll., *JHEP*, 05, (2008)

(b) J. Bijnens and K. Ghorbani., *JHEP*, 11, (2007)

(c) S- P. Schneider et al., *JHEP*, 028, (2011)

(d) WASA-at-COSY coll., *Phys. Rev.*, C90(045207), 2014

(e) Peng Guo et al., *Phys. Rev.*, D92(05016), (2015)

(f) KLOE coll., *JHEP*, 019, (2016)

(g) Peng Guo et al., arXiv: 1608.01447v3, (2017)

- WASA-at-COSY: $Q = 21.4 \pm 1.1$[e]
- KLOE: $Q = 21.7 \pm 1.1$[g]
- **Dalitz Plot Analysis and determination of Q for $\gamma p \to p\eta[\eta \to \pi^+\pi^-\pi^0]$ with the CLAS G12 data set**

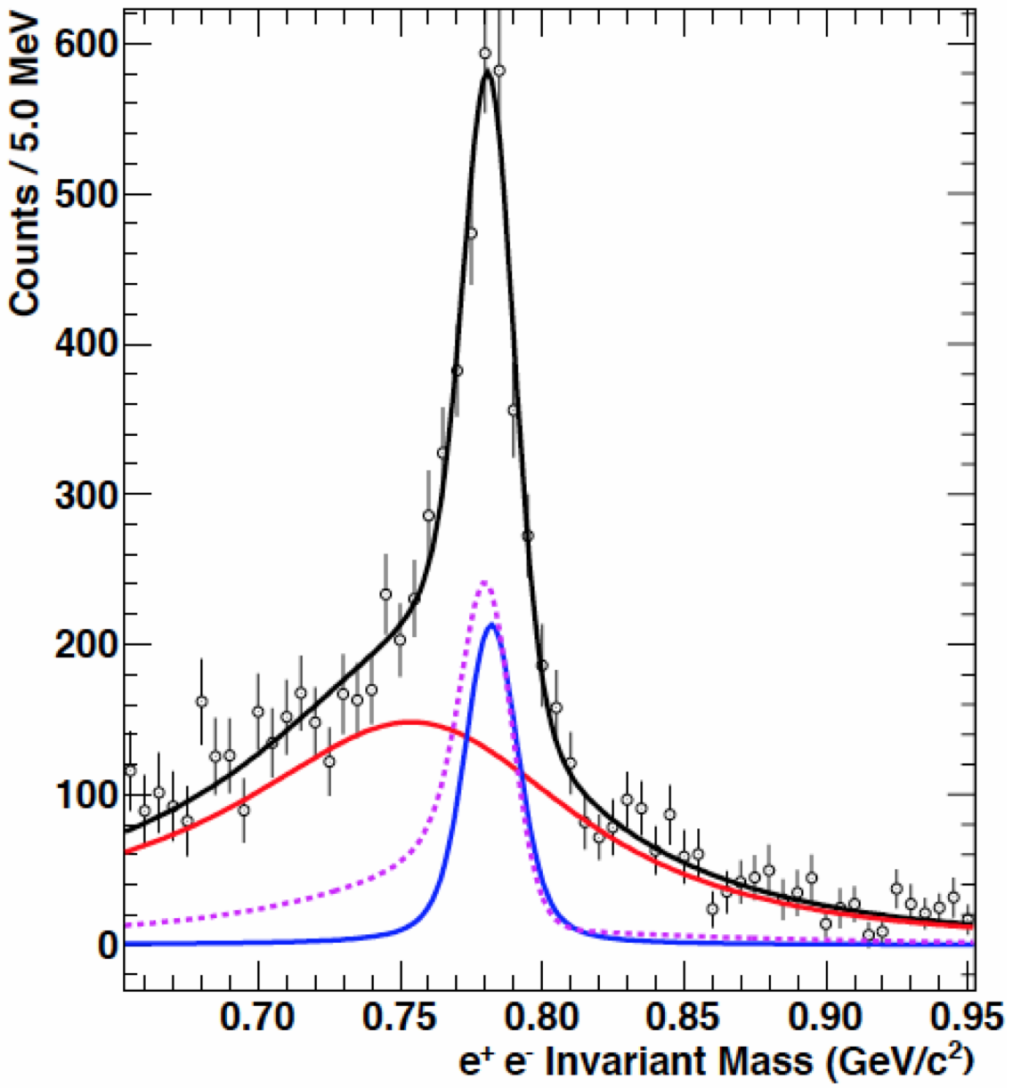
omega xtras

simulation ω decays

PLUTO event generator
incl. Bremsstrahlung beam profile and ω angular distribution
event cut:
=2 g7leptons, event vertex, TOF, pass all acceptance cuts, pi0 missing mass

decay chain	thrown events	BR of chain	events after event cut	after normalization	
$\omega \to \pi\, ee \to 2\gamma\, ee$	2.19995e+06	7.60937e-04	4597	494.7	signal (need QED, too)
$\omega \to \pi_D\, ee \to \gamma\, 2(ee)$	1.93004e+07	9.0398e-06	26861	3.8	
$\omega \to \pi\, \gamma \to 3\gamma$	2.14984e+07	8.18254e-02	1148	1339.7	need more stats
$\omega \to \pi_D\, \gamma \to 2\gamma\, ee$	1.9999e+07	9.72072e-04	2548	38.0	
$\omega \to ee$	1.99998e+07	7.28e-05	3858	2.9	need ρ/ω line shape
$\omega \to \eta\, \gamma \to 3\gamma$	2.00004e+07	1.81286e-04	148	0.4	
$\omega \to \eta_D\, \gamma \to 2\gamma\, ee$	2.00004e+07	3.174e-06	3209	0.2	

ρ-ω interference



PoS Hadron2013 (2013) 176
JLAB-PHY-13-1839

based on same data
CLAS g12 experiment

targeted channel
γ + p → p + ee (in the ρ regime**)**

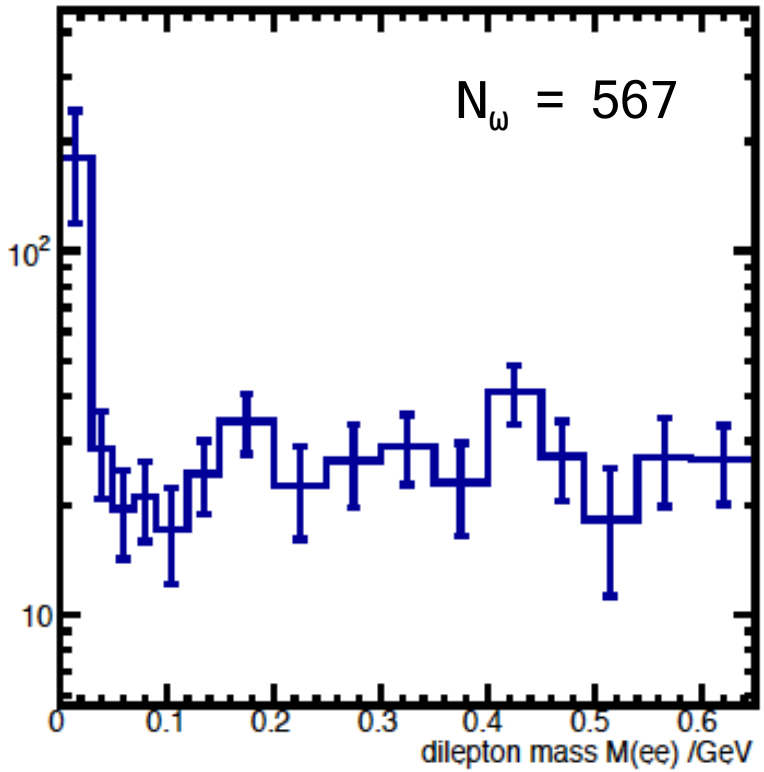
event selection via

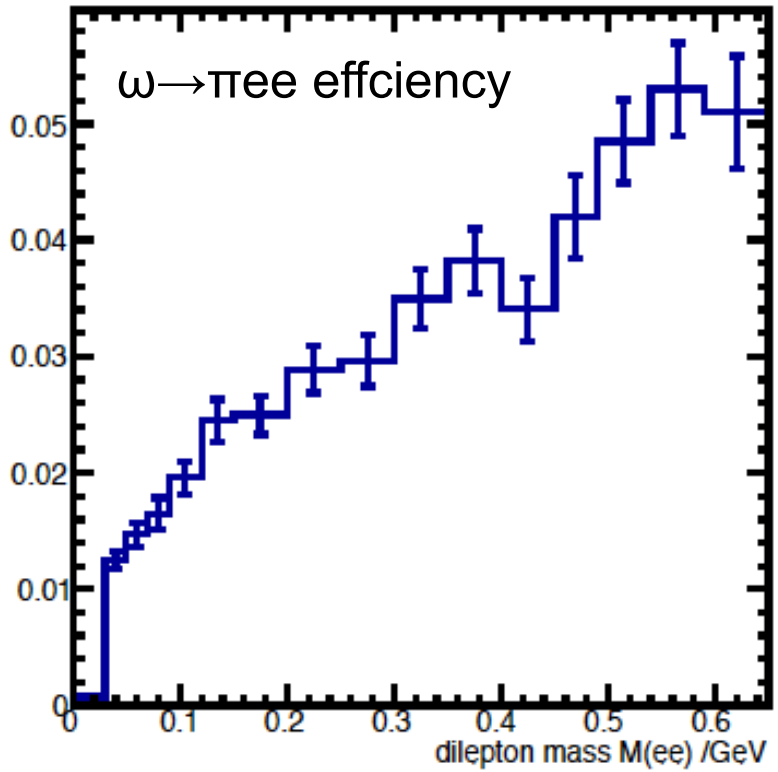
- PID dilepton
- missing mass MM(ee)=M(p)

interference
causes low-mass tail

ω-π^0 Transition Form Factor

ω→πee efficiency correction





background subtracted signal:
integrated over tagger range
1.1-5.5GeV

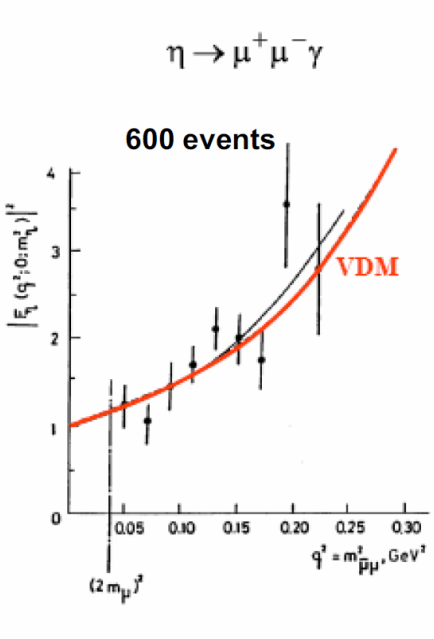
PLUTO event generator for CLAS includes Bremsstrahlung and ω cross section

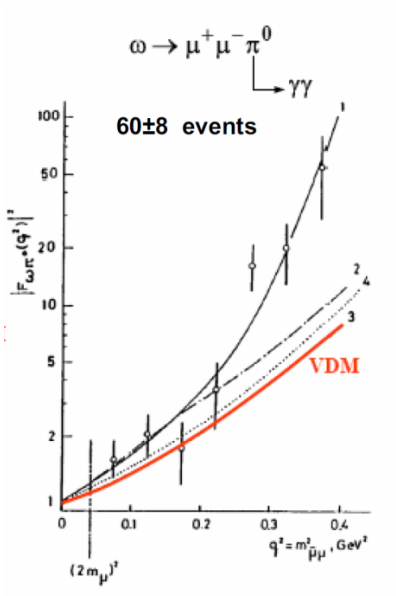
TFF other mesons xtras

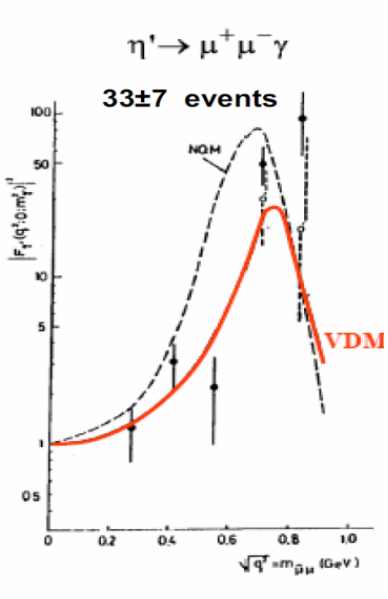
(OLD) WORLD DATA SET: CONVERSION DECAYS

L.G. Landsberg, Electromagnetic decays of light mesons

IHEP in 1978—1980 on the “Lepton-G” spectrometer







for ω meson, clearly additional mechanisms apart from standard VMD

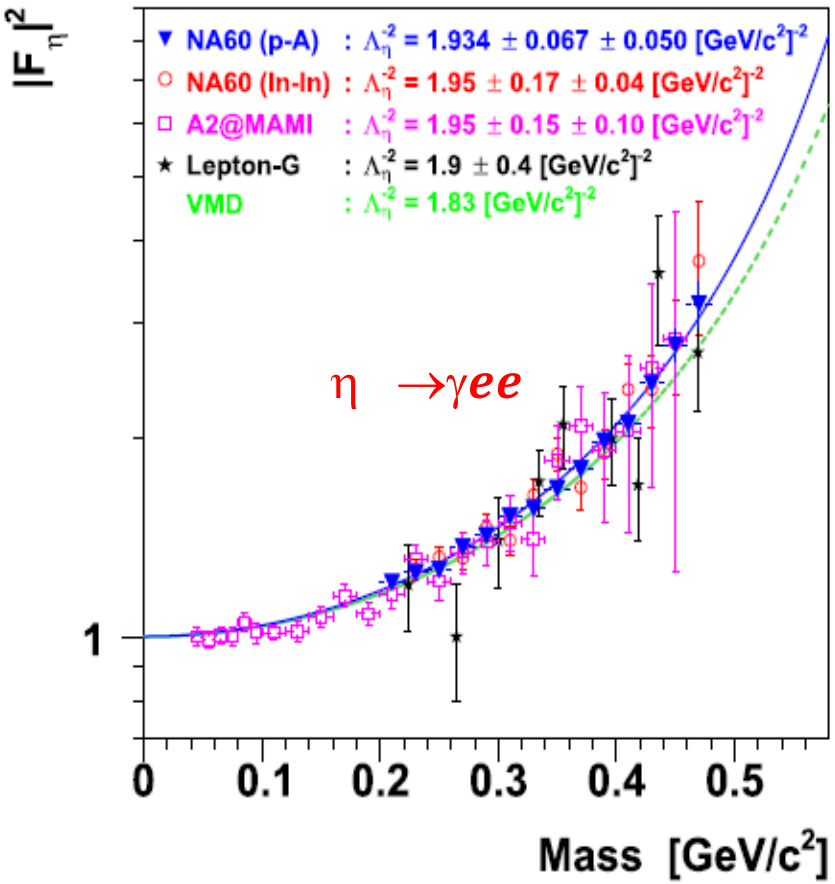
(black curves are fits to the data)

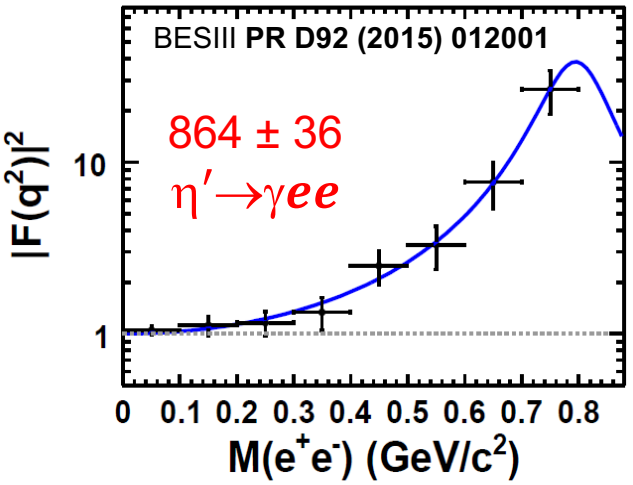
- confirmed by NA60 AA reactions, S. Damjanovic, PLB 677 (2009) 260
- confirmed by NA60 pA reactions, A.Uras, J.Phys. Conf.Ser.270(2011) 012038

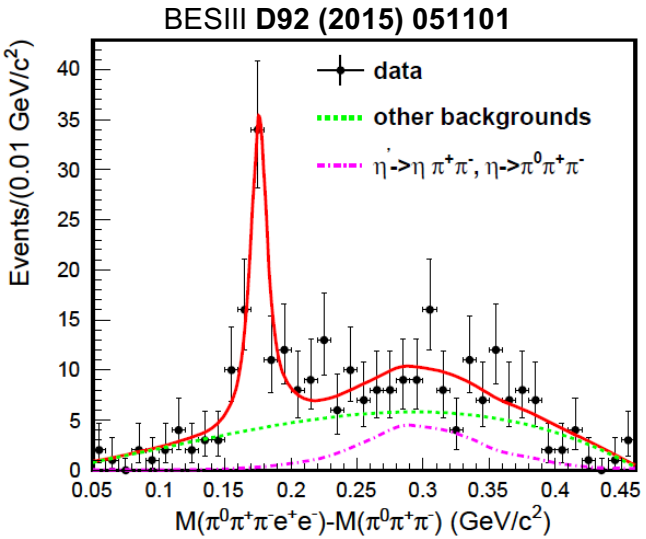
different experimental approach: elementary reactions, using di-electrons

NEW DATA SETS: η AND η‘

A2 **Phys.Rev. C89 (2014) 044608**
NA60 **Phys.Lett. B757 (2016) 437**



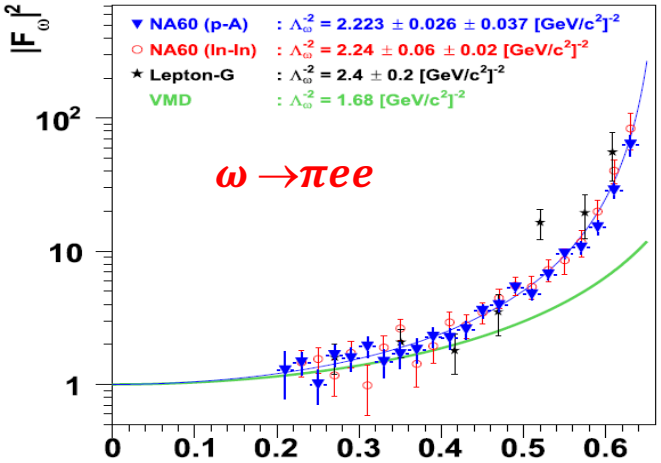


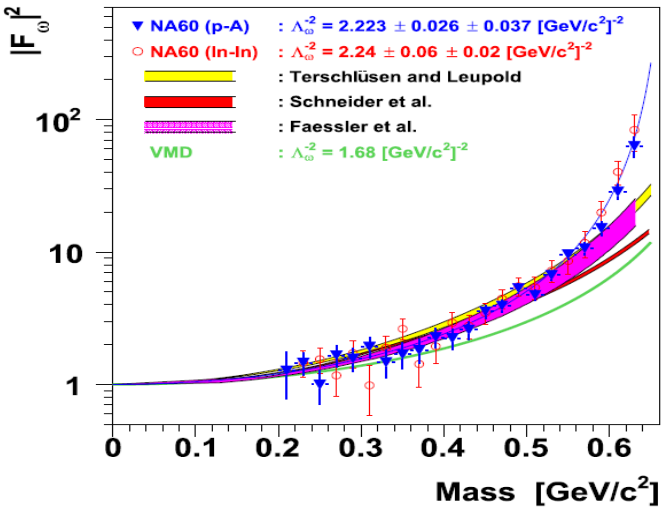


BR$(\eta' \to \omega ee)$ $(1.97 \pm 0.34(\text{stat}) \pm 0.17(\text{syst})) \times 10^{-4}$

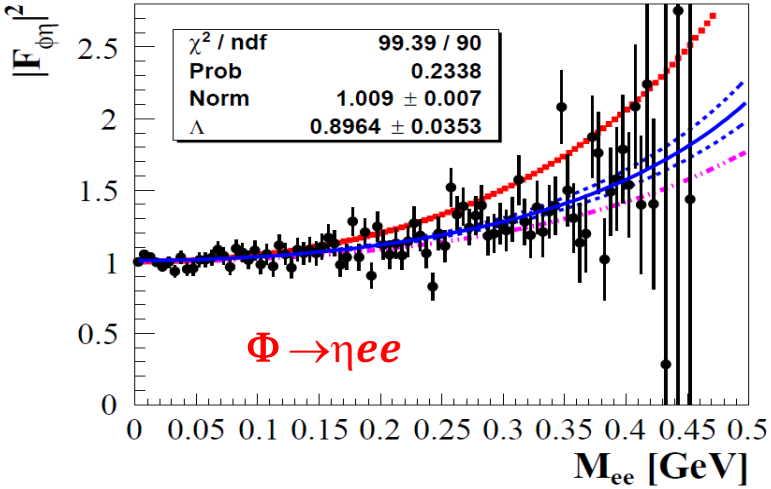
NEW DATA SETS: ω AND Φ

NA60 **Phys.Lett. B757 (2016) 437**

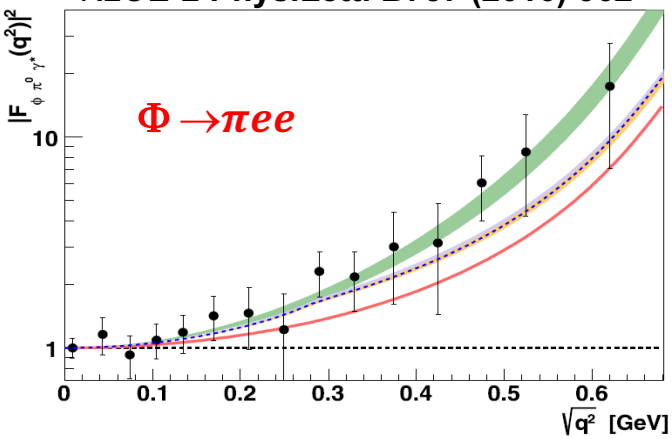




KLOE2 **PLB742 (2015) 1**



KLOE-2 **Phys.Lett. B757 (2016) 362**



puzzle not solved yet